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COMBUSTION INSTABILITY WITH PARTIAL LENGTH

ACOUSTIC LINERS

(NASA-CR-145976) COMBUSTION INSTABILITY  
WITH PARTIAL LENGTH ACOUSTIC LINERS

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Report of Research

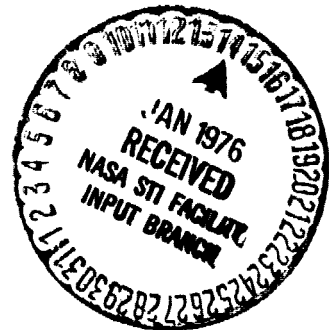
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## Introduction

This report gives a brief summary of the work completed during the past year at Colorado State University with the support of NASA Grant NGR-06-002-095. The overall goal of this project is the development of analytical techniques and numerical methods for the prediction of the stability behavior of liquid propellant rocket combustors with partial length acoustic liners, injector face baffles and nonlinear combustion responses. In accordance with this overall goal effort during the past year was focused at three primary objectives. These were:

- 1) Extension of the Green's Function integral-iteration technique previously developed (Reference 1) so that nonlinear three dimensional wave propagation effects could be included in stability predictions.
- 2) Development of an analytical technique and a computer program for the prediction of the damping effects caused by injector face baffles.
- 3) Inclusion of a nonlinear, wave distortion dependent, combustion response model in the global stability analysis and determination of its effect on combustor stability.

Once completed it is intended that the analyses and computer programs which result be combined (along with previously completed work, References 1, 2, 3) to form a global stability model sufficiently comprehensive as to be able to predict frequency, decay rates, and wave-forms for a wide range of combustor and absorber designs.

Progress in the year's three main areas of effort, Nonlinear Wave Propagation, Baffle Analysis, and Wave Distortion Response are summarized separately below.

### Nonlinear Wave Propagation

It is well known that nonlinear wave propagation effects cause significant changes in pressure waveforms (distortion, steepening) and in combustor stability behavior (triggering, nonlinear stability limits). The importance of the inclusion of these effects in any general stability model is thus clear. Also, since nonlinear boundary conditions are to be considered at both the combustion zone and acoustic absorber, a nonlinear treatment of wave propagation is necessary for consistency. A method for including these effects (at least for moderate amplitude waves) has been developed and became available in March 1975 as NASA CR 134767, "Suppression of Nonlinear Oscillations in Combustors with Partial Length Acoustic Liners". The approach employed expansion of the gasdynamic and combustion parameter into power series ordered in the pressure wave amplitude  $\epsilon$ . Substitution into the governing equations and separation according to powers in  $\epsilon$  yielded linear sets of partial differential equations which were transformed into integral equations using a Green's Function approach and solved through 3rd order in  $\epsilon$ . Solutions indicated the existence of both triggering regions and nonlinear stability limits. Nonlinear three dimensional waveforms were also determined. Details are available in the Contractors Report mentioned above.

A second approach to the problem is to include the nonlinearities in the equations through a successive approximation method which does not

require formal expansion in powers in  $\epsilon$ . This second approach is better suited to the inclusion of wave distortion effects introduced by the vaporization limited combustion model discussed later in this report. Consequently, some considerable effort during the past year has been spent in detailing the equations and integration procedures necessary for this approach. Basically, it is assumed that a single frequency and mode of oscillation are characteristic of the nonlinear oscillations. The frequency, decay rate, and distorted waveforms are determined by successively including the nonlinear integral terms appropriate for the combustion zone, absorber surfaces, nozzle exit plane and volumetric nonlinear convection.

In the end this approach will lead to a simpler overall model in which any nonlinearities, or source terms may be included or left out at the users discretion with no fundamental computer program changes.

#### Baffle Analysis

The purpose of this work is the development of a model for injector face baffles which predicts both their damping influence and their frequency shifting capability. During the past year two and three dimensional combustor models characterized by concentrated combustion sources at the injector and constant Mach number nozzles as well as injector face baffles of arbitrary length and number have been developed. An eigenfunction matching technique is used to solve the linearized partial differential equations describing the unsteady flow field present in both models. Boundary layer corrections which are critically important in the production of mechanical energy dissipation in the high velocity flow

around the baffle tips are then calculated using the inviscid eigenfunction matching solution as the "outer" flow. An integral stability relationship (of the Cantrell-Hart type) is then used to predict combustor frequency of oscillation and decay rate for the combined main chamber-baffle cavities system.

Results of this analysis agree qualitatively with experimental observations (quantitatively with respect to frequency predictions) and indicate that sufficient dissipation exists in the boundary layer around the baffle tips to be the primary mechanism of baffle damping influence.

Results of a portion of this work were presented at the 12th ICRPG Combustion Meeting and will be available in the Proceedings of that meeting. In addition a Contractors Report is under preparation which will include details of the technique as well as a computer program suitable for stability predictions. This report should be available early this year.

#### Wave Distortion Response

The goal of this portion of the project is the evaluation of the effects of a vaporization limited combustion response zone which is sensitive to wave distortion influences on combustor stability. The initial approach to this problem involved considering linear wave propagation and nonlinear combustion response, for simplicity. Also, the combustion response model was expanded, analytically, into first and second harmonic components for travelling transverse wave motions. Stability was then evaluated using a modified form of the integral-iteration Green's function method. Initial results (reported partially in last year's annual report)

indicated a strong driving influence and considerable second harmonic content due to the combustion zone response. This year due to certain anomalies in the results when extension to the standing modes was attempted, the original problem (travelling waves) was redone using a complete numerical evaluation of the response term. When this was done, a much lower value for driving was found, though considerable second harmonic content was still generated. The two approaches were then checked carefully for errors and both errors and regions of non-convergence for the analytical (original) approach were found. When the errors were corrected and calculations restricted to regions where the expansion was reasonable, good agreement between the two methods occurred.

The explanation for the reduced driving effect now predicted lies in the phasing with which the second harmonic component is generated. That is, if a linear first harmonic waveform is used in the response function for pressure and velocity, the second harmonic content thereby generated is of the wrong phase to produce significant nonlinear driving. This is different from the response situation for the vaporization model in open loop performance in which the phase between first and second harmonic components may be specified. Along these lines an attempt was made to analyse the situation for combustors of a geometric design such that linear 1st and 2nd harmonic modes could exist simultaneously (as in the work of Purdy et.al.) The iteration technique in the case, however, has so far proved non-convergent, i.e., the solution will not converge to a single frequency and decay (growth) rate. Work is continuing to see if these difficulties can be overcome.

Since, with this "improper phasing", the driving effect of the

combustion zone is so low as to be only marginally destabilizing, a time lag was introduced into the combustion response model. Basically, this means that the time during which most mass is given off by a droplet is neither long nor short compared with the period of oscillation. This modification has produced significant increases in the driving produced by the combustion zone. For some values of the time lag overall growth rates for the combustor are quite large. The time lag here, it is to be remembered, is related to the droplet lifetime and is not a heuristic parameter as is the Crocco  $n, \tau$  model.

A possible second means of introduction of properly phased second harmonic content is from the nonlinear terms in the governing wave equation. An effort is currently underway to examine this possibility. Essentially a marriage of the combustion response model with the nonlinear wave propagation work (of the successive approximation type) is required.

#### References

- 1) Mitchell, C. E., Espander, W. R., and Baer, M. R., "Stability of Combustors with Partial Length Acoustic Liners," NASA CR-120899, 1972.
- 2) Baer, M. R., Mitchell, C. E., and Espander, W. R., "Stability of Partially Lined Combustors with Distributed Combustion," AIAA Journal, Vol. 12, No. 4, April 1974, pp. 475-480.
- 3) Espander, W. R., Mitchell, C. E., and Baer, M. R., "Suppression of Nonlinear Oscillations in Combustors with Partial Length Acoustic Liners," NASA CR-134767, March 1975.